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ROCKET SOUNDING OF THE UPPER ATMOSPHERE

BY

Homer E. Newell
National Aeronautics and
Space Administration

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AREAS OF RESEARCH

Rocket sounding contributes to many areas of research. The most important contributions are those for which the rocket is required. Among these are observations of the radiations which enter the earth's atmospher but cannot penetrate to the ground. Also included are measurements of properties and conditions of the atmosphere that exist at high altitude where they cannot be observed from the ground or the lower atmosphere. Without the rocket observations, there is much about the upper atmosphere and the incoming radiations that would be left entirely to speculation. It is the intent in this section to review some of the important areas to which rocket sounding has contributed and to which it can contribute. particular stress will be laid upon the problems yet to be solved. It will be seen that there is much yet to be done, and that there is a real need for good ideas and effective methods of attack on the various problems.

Earth' Atmosphere

The earth's atmosphere presents one of the most exciting challenges of geophysics. There are many aspects of the atmosphere that are intensely interesting in themselves. The whole subject of meteorology, which has direct bearing on our everyday living, is one of great complexit and fascination. The high atmosphere, too, has a fascination of its own, but is quite different. Whereas in the lower atmosphere, water vapor plays a major role, the "weather" of the upper atmosphere is based primarily on electrical and photochemical changes. The ionosphere, its composition, its relations to solar radiations and activity, its dynamics, its connections with magnetic storms and radio blackouts, are all intensely absorbing. The motions of the atmosphere, not only those near the ground which we experie day in and day out, but those in the higher atmosphere, are themselves a subject of both interest and importance. But, the principal fascination is that all this topics, and more too, concern a single entity that comprises the earth's atmosphere. It is understanding this total entity and all the interrelationships between the various aspects of the atmosphere, their changes with time and throughout space, that makes up the big problem.

To solve this overall problem, one has to fit together into a consistent theory the observed facts about the structure, motions, and chemistry of the high and low atmosphere, about the meteorology of the lower atmosphere, about the energy inputs into the atmosphere from the sun in the form of electromagnetic radiations and particles. There are other, lesser, energy inputs also,such as the solar and lunar tides. In addition there are effluxes of energy to be taken into account.

Hand in hand with the effort to understand the atmosphere as it is today goes the effort to unveil the mysteries of its origin. The subjec broadens and increases in interest when one considers the relations betwee the earth's atmosphere and those of the other planets. With satellites and space probes to collect information on the atmospheres of the other planet while sounding rockets examine the eaath's atmosphere, there opens up the opportunity to compare, to seek out similarities and differences. The comm study of terrestrial and planetary atmospheres will lead to a better under standing of the earth's atmosphere.

There are two principal aspects to the job of developing an understan ing of our atmosphere. First, there is the collection of data. This task has been underway for a long time . In the last 15 years the sounding rock has contributed greatly, particularly in the collection of data on the upper atmosphere. Much remains to be done. Secondly, there is the task of assimilating the data into a correct picture of the whole atmosphere and its behavior. This is a task worthy of the best that theorists can devote to it.

Many methods have been used to collect data on the atmosphere. There are ground observations, balloon measurements, and experiments with aircraft, rockets, and satellites. All these approaches are important and

and productive. Since, however, the subject of this paper is rocket sounding, we shall confine our attention to the rockets.

Structure. In considering the atmosphere it is natural first to look at the structural properties , namely, pressure, temperature, and density. The pressure and density vary essentially exponentially with height. But both pressure and density profiles depart from a pure exponential because temperature varies with altitude. Above the E-region, composition changes also have an appreciable effect. The exponents of the pressure and density functions show a marked change above about 130 km. The atmosphere exhibits differences at different latitudes, especially at high altitude. In the auroral zone at high altitude, the atmosphere is much hotter than over the temperate and equatorial regions. Likewise, the auroral zone densities are higher than those in lower latitudes. This effect is perhaps due to the influx of the energetic particles that cause the aurora. These particles contribute the energy to the atmosphere that accounts for the higher temperatures and densities. As may be expected, there are day to night differences, particularly at the very high altitude, where the diurnal variations are quite large. This in turn means that the atmosphere exhibits differences in longitude that are connected with the solar position. Seasonal differences are, of course, quite marked in the lower atmosphere, but are not well pinned down. If, as has appeared likely of late, solar particles have a marked influence on atmospheric behavior, then one expects that there will be important variations connected with the solar cycle.

The rocket can provide much needed data on atmospheric structure. Measurements should be continued throughout a complete sunspot cycle. Measurements are needed all over the world to exhibit geographic variation, as well as changes with time of day and season. There is particular importance in determining what relations may exist between the meteorology of the lower atmosphere and the activity of the upper atmosphere. Cooperat rocket firings designed to give simultaneous, or specially related, observations on the upper atmosphere at different geographic locations would be of great value.

Composition. The gross composition of the earth's atmosphere is known from direct measurements in the lower altitudes. The lower atmosphere is characterized by the presence of water vapor and only a trace of ionization. In the high atmosphere, on the other hand, there is virtually no water, but much more ionization. The lower portion of the atmosphere is thoroughly mixed, this mixing extending up to roughly 100 km. atmospheric constituents begin to show a diffusive separation with altitude. Below 80km. there is very little variation in the atmospheric composition, the most notable exception being the formation of a small amount of ozone. In contrast, above 80 km. there are marked changes. Oxygen dissociates into the atomic form, with the result that there is very little molecular oxygen above 150 km. Moreover, the diffusive separation referred to above tends to emphasize the lighter constituents at the higher altitudes. Thus the amount of helium should increase with altitude above 100 km. At the top of the atmosphere, the principal constituent is believed to be hydrogen. The principal ions are the positive molecular oxygen ion and the positive nitric oxide ion in the E and F1 regions. The positive ion of atomic oxygen becomes increasingly important with increasing height, becoming dominant in the F2 region.

Most of the data on the upper atmosphere described above were obtained by means of sounding rockets. There is still much for the rockets to do. Adetailed investigation of the distribution of ozone up to and above 60 km should be initiated to determine the geographical and temporal variations. Particular emphasis should be directed toward seeking out relationships between ozone behavior and weather. More information is needed on the photochemical processes occurring in the very high atmosphere. There is opportunity, with sounding rockets, for conducting experiments in the high atmosphere with sodium vapor clouds or releases of other chemicals. These experiments give one a means of determining photochemical reactions, winds diffusion rates, recombination coefficients, energy and charge exchange processes, collision cross sections, and even densities. An important subject that has received but little attention to date concerns the minor constituents of the atmosphere, both neutral and charged. There is need t investigate the diffusion region of the high atmosphere in detail. In particular, the hydrogen region has received but little attention so far. The differences in the high atmosphere between the auroral region and the temperate and equatorial zones should be investigated thoroughly. In particular, the relative roles of electromagnetic radiation and particle radiations in influencing atmospheric behavior should be investigated in detail.

Ionization. Observations with rockets and other methods have succeeded in showing that the ionization of the atmosphere in the ionosphere remains dense from below the E region to the maximun of the F2 region. The decline in ionization above the maximun of the F2 region is very slow, there being three or more times as much total ionization above as below. The normal D region is caused by solar ultraviolet radiation in the Lyman-alpha line of hydrogen at 1216 A. The enhanced D region, extending much lower in the atmosphere than the normal D region, has been shown to be caused by hard X-rays emitted by the sun at the time of a flare. The principal ions in the E region, besides the negative electrons, are the positive ions of molecular oxygen and nitric oxide. In the upper levels of the E region and the F1 region the nitric oxide ion becomes increasingly dominan The positive ion of atomic oxygen increases in relative abundance with increasing altitude until it becomes predominant in the F region. In middl latitudes, at sunspot maximun the summer noon electron density is about 2×10^6 electrons per cubic centimeter at F2 maximun. This ionization intensity decreases by a factor of ten at the time of sunspot minimum.

There are many more details about the ionosphere that have been obtained by rocket observations. In particular , there have been measureme of the ionosphere in the auroral zone. Nevertheless, more observations are required of the differences between polar, auroral, temperate, and equatorial ionospheres. Special attention to the higher regions of the ionosphere, particularly beyond the F2 maximun, is required. Day-night differences in the ionosphere have as yet not received adequate attention. In addition to measurements or the normal ionosphere, study of unusual conditions is important. Investigations should be made of sporadic E, spread F, and ionospheric inhomogeneities. Particular attention should be devoted to simultaneous observations of solar activity and ionospheric effects.

Motions. Atmospheric motions, winds, and turbulence, have long been studied in the lower atmosphere. They comprise a fundamental part of the weather picture. In the upper atmosphere, observations of meteor trails, both by visual, photographic, radio, and radar techniques, have yielded much information on upper winds. Ionospheric drifts have been investigated by radio techniques. Most recently rockets have been used in the investigation of high altitude winds. Grenades ejected from rockets and exploded generate sound waves which traverse the atmosphere at a speed characterist of the ambient atmospheric temperature. Observations of the transit times of the sound waves from the explosion point to listening stations on the ground provide, therefore, a means of determining atmospheric temperature at high altitude. Winds in the upper regions influence the speeds of the sound waves from the grenades. By their effect on the sound speeds these wind speeds can also be measured. The technique is applicable to altitudes from balloon ceilings to around 90 km. reaching to as high as 250 km., sodium-clouds ejected at twilight have proven a powerful technique in observing diffusion, wind speeds, wind shears, and turbulence. The rising or setting sun, illuminating the sodium cloud from the side, causes it to glow in the familiar sodium D yellow lines. This visible cloud can then be observed both visually and photographically. The rocket observations have shown distinct seasonal trends in the upper winds. Winds appear strong and from the west in the winter and relatively weak and from the east in summer. There are probably diurnal variations superposed on this seasonal behavior. Morning winds appear to be easterly and evening winds westerly. Considerable turbulence and marked wind shears are observed in the E region of the ionosphere; at the higher altitudes large wind speeds are observed, but the variation with altitude is quite slow.

The rocket observations on atmospheric motions have been confined to the northern hemisphere to date. Measurements have been made at White Sands, New Mexico; Cape Canaveral, Florida; Wallops island, Virginia; Fort Churchill, Canada; the Sahara; and Woomera, Australia. There is a need for similar observations in the southern hemisphere and on the equator. So far the data obtained are scattered and rather meagre. More information is needed on both daily and seasonal variations. A thorough coverage is required from the equator to both poles. In such observations an international cooperative program would be of great value. The sodium vapor cloud technique particularly lends itself to cooperative programs. The grenade technique is more difficult to use but might possibly be employed in cooperative observations for the lower altitude range. More attention should be paid to obtaining data on vertical movements within the atmosphere on turbulence, and on diffusion.

Aurora. The evolving picture of the earth's radiation belts lends support to the belief that the belts are the immediate source of particles that give rise to the aurora. It is clear that the aurora is associated with activity on the sun. Although the visual aurora can be observed and studied from the ground, the rocket is needed to investigate the aurora from within to measure the ultraviolet aurora and to observe the particle radiations that create the phenomenon. Rockets within the aurora, hand in hand with ground observations on the one side and satellite observations on the other, provide a powerful method of attacking this most interesting problem. There is, of course, need for information on the nature and energy of the particles within the atmosphere that are associated with aurora. It will be of interest to observe where these particles are stopped, and the radiations to which they give rise: x-rays and ultraviolet radiations must be studied in rockets and satellites, whereas the visible radiations can also be observed from the ground.

Airglow. The airglow is a faint radiation that is continuosly given off by the earth's high atmosphere. The airglow is comprised of lines and bands of the atmospheric constituents. The well-known 5577 A green line of atomic oxygen is included. Other wavelengths are also observed, including the sodium D yellow lines. Although the airglow spectrum is similar to that of the aurora, the airglow is very much fainter than the auroral radiations, and the mechanism giving rise to the airglow is different from that giving rise to the aurora. The airglow is a fluorescence and phosphorescence of the upper atmosphere molecules. It is evidence of photochemical activity in the high atmosphere, and this is the principal importance of the airglow to the atmospheric researcher. The airglow also furnishes clues to atmospheric composition.

It is possible from ground-based observations to obtain great quantities of data on airglow intensities, geographic distributions, and variations with time. However, great difficulty attaches to determining the heights from which the airglows originate. The rocket on the other hand can very quickly determine the actual heights of origin of the airglow radiation. Rockets in cooperation with ground-based photometric observations can provide a strong attack on the problem of the airglow. Determination of longitudinal, latitudinal, temporal, and altitude variations of the airglow are of particular importance. The chemical activities associated with the airglow radiations are likewise essential pieces of information. In addition to observation of the natural airglow phenomenon, the rocket provides a means for experimenting with artificial airglows. These can be produced by ejecting various materials into the high atmosphere. For example, sodium or potassium vapor clouds ejected into the high atmosphere at the time of the setting or rising sun provide a glowing cloud which flaoresces under the radiation from the sun. Ethylene gas ejected into the ionosphere glows because of photochemical reaction with atmospheric constituents already there. The same is true of nitric oxide ejected into the high atmosphere. A combination of observation of the natural airglow and experimenting with artificial airglows should prove to be a powerful tool for investigation of photochemical and ionization processes in the high atmosphere.

External influences. There are powerful influences acting upon the earth's atmosphere. The sun's electromagnetic radiation brings a considerable amount of energy into the atmosphere. This radiation has a pronounced effect upon the lower levels, giving rise to the varied manifestations of weather and climate. It appears that the ultraviolet radiations also influence the lower atmosphere. It is certain that they have, along with solar x-rays, a pronounced effect upon the high atmosphere, giving rise to the ionosphere, heating, upper winds, airglows, etc. For over half a century particle radiations from the sun have been taken as the cause of the aurora, magnetic storms and special ionospheric effects. Recent observations of these phenomena together with investigatio of the radiation belts and the interplanetary medium in the vicinity of the earth have confirmed and clarified to some extent the role of particle radiations in connection with the aurora, magnetic storms, and special ionospheric effects. The indication, however, is that the influence of particle radiations upon the earth's atmosphere is even broader than was earlier suspected. There are signs that these particle inputs may also have their influence upon the weather. Although these last indications are by no means confirmed, they are of sufficient import as to deserve careful investigation. The influence of the electromagnetic radiations from the sun are direct and immediate. Some of the particle influences on the atmosphere ocurr immediately upon arrival of the particles, an hour or a day after the solar event. Other particle influences are delayed by storage of the particles in the radiation belt for long periods of time.

The opportunity now exists with satellites and space probes to mount a vigorous attack on these various problems. The sounding rocket can be used to handle those studies that must be conducted within the atmosphere between balloon altitudes and satellite heights. One needs further detail on the population of the radiation belt, particularly the low energy particles. One needs to determine the time history of solar inputs to the vicinity of the earth, the associated behavior of the radiation belt, and the associated effects upon the aurora, weather, the ionosphere, radio communication, and the magnetic field. The connection with radio blackouts and magnetic storms is of great practical importance.

The earth's magnetic field is of especial importance because of its influence on charged particles. The charged particles in the earth's radiation belt are held there because they are trapped by the earth's magnetic field. Likewise, ions and electrons in the earth's ionosphere are influenced by the presence of a magnetic field. This field affects conductivity, diffusion, and current flows in the ionosphere. Similarly the magnetic field itself is in turn affected by the ionospheric current flows. Whereas the artificial satellite is probably the best device for making long-term and detailed studies of the earth's magnetic field and the radiation belt, on the other hand the sounding rocket is best fitted for investigating ionospheric current flows, and conductivities and diffusion, since these are associated with the atmosphere below normal satellites altitudes.

Cosmic rays make some input into the atmosphere. They are the source of much of the ionization existing near the ground. But other than that, the cosmic rays probably have negligible influence on the total atmosphere behavior. Sounding rockets provide an effective tool for their study, although balloons and satellites are probably more useful in this connecti The major interest in cosmic rays is in the radiation itself, and its cosmological implications, rather than in its effects upon the earth's atmosphere. Solar cosmic rays, or solar proton beams, may be of importance in connection with effects upon the polar atmosphere.

Cosmic dust is constantly streaming into the earth's atmosphere. It probably contributes some to atmospheric ionization, particularly at the lower E region altitudes. It may contribute to control of rainfall, as suggested by Bowen's work. Sounding rockets are suited to an observation of the presence of cosmic dust within the atmosphere. Artificial satellite and space probes are, however, best suited to tackle the problem of the flux of cosmic dust in interplanetary space.

Gravity exerts an influence on the earth's atmosphere. The influence of the earth's gravity is seen in the retention of the earth's atmosphere, in convection, and in diffusive separation at the higher altitudes. The moon's and sun's gravitational attractions exert their influence primarily through tides produced in the atmosphere. While the rocket is not particul ly useful for studying gravity itself, as is the satellite or space probe, nevertheless the rocket provides a means of investigating the atmosphere's behavior under the influence of tides and other gravitational phenomena.

Interdisciplinary attack. An understanding of the earth's atmosphere will be achieved only by bringing together in a coherent and illuminating fashion the facts revealed by the masses of observational data obtained in the various fields listed above. The problem is broader than rocket research alone. The data must be assembled from all sources: ground observations, rocket studies, satellite measurements, balloon experiments. These data must be melded together by statistical analysis, and by descriptive theory to get the total picture. It is of particular importanc to bring out the inter-relationships existing between various aspects of the atmosphere. How real, for example, are the effects of solar particles on weather? Are there any significant relations between the upper atmosphe and the lower atmosphere? What features of the atmosphere and its behavior can contribute to an improvement in weather forecasting, perhaps to weathe control? In what way are the various features of the high and low atmosphe associated with climate and climatic trends? What features of the atmosphe may be useful in forecasting communications conditions, radio blackouts, and disturbed conditions? An important feature of this work is that theory and observation should be neither separate nor sequential. They should go consciously hand in hand. There should be a continuos feedback from theory to experiment, and experiment to theory. The guidance provided by theory should strengthen and make more effective the observational work. In return the observational data gives reality to theoretical results.

The broadness of the problem of the earth's atmosphere is clearly brought out by the wide range of disciplines involved. As a consequence there will often be a need for correlated, cooperative observations in many disciplines. A program designed to attack the problem of the atmosphere will naturally include a broad spectrum of experiments in the different disciplines, including simultaneous observations of different types. But the breadth of the atmospheric problem is also geographic. We are talking about a whole earth's atmosphere. Hence, there is a great opportunity for international cooperation to observe the atmosphere, not only at various times, but at many places. As during the International Geophysical Year, the broad geographic attack on the investigation of the earth's atmosphere should continue.

The sun

We have already referred to the importance of the sun and its radiations in connection with the investigation of the earth's atmosphere. In studying the atmosphere, the facts about the sun are important because of their connection with the behavior of the atmosphere. The sun looms in importance as the major source of energy received by the earth.

But the sun is scientifically important in its own right. It is a star the nearest star. It provides us with our only opportunity to study a star close at hand. Beneath the earth's atmosphere, we cannot make the most of this opportunity. The atmosphere cuts off wavelengths below roughly 2850 A. In addition, it distorts those wavelengths that do penetrate to the ground. Equipment carried aloft in balloons can extend observations somewhat into the ultraviolet. More importantly, such balloon-borne equipment can be carried above the atmospheric levels that cause most of the distortion. Telescopes carried in balloons can be used to make precision observations and photographs of a clarity that cannot be obtained at the ground.

Satellites can put the rest of the atmosphere behind, extending observations into the ultraviolet, x-ray, and even shorter wavelength regions. Above the ionosphere, additional parts of the radio spectrum can also be observed. Satellite telescopes can collect data in all the wavelengths. In particular, such satellite-borne telescopes with virtually unhindered seeing conditions, can be used for precision and long term observations. All of these things can be accomplished when the necessary engineering of telescopes and stabilization systems has been worked out.

What, then, is left to the sounding rocket in this area? The sounding rocket can be used for initial surveys in a given area, to determine intensities, and the presence or absence of phenomena of interest in given wavelength ranges. The sounding rocket provides an inexpensive means for carrying out such exploratory work. It can be used for testing and calibrating equipment before such equipment is used on satellites. The Naval Research Laboratory, University of Colorado, and Goddard Space Flight Center groups have been very succesful in the use of the rocket for investigating the sun. Solar radiations have been measured down to the hard x-ray wavelengths in the neighborhood of 1 A unit. Detailed spectra have been obtained into the far ultraviolet including the entire Lyman-alpha series and some of the continuum beyond. Rense has photographed the He-II 304 A resonance line. Solar x-rays are enhanced and hardened at the time of a solar flare, but little effect is observed in the Lyman-alpha line of hydrogen at 1216 A. The x-ray radiations indicate million degree temperatures in the solar corona. The normal Lyman-alpha hydrogen line is narrow, showing structure. As shown by Tousey, down to between 1800 A and 1550 A the solar spectrum is similar in character to that of the visible wavelength region, namely a continuum with Fraunhofer lines. Below 1800 A the spectrum exhibits more and more emission lines, in which the 1216 A Lyman-alpha line of hydrogen is the brightest feature. As mentioned above, the entire Lyman-alpha series and the continuum beyond appears in the spectrum, but with Lyman-gamma suppressed, apparently by absortion in the earth's atmosphere The Naval Research Laboratory group has obtained photographs of the sun's disk in both Lyman-alpha and x-ray wavelengths.

The important role of the rocket is in collecting data that cannot be obtained at the ground. There is a need for more information on the sun's energy output in x-ray, ultraviolet, and other wavelength regions. There is particular need to measure these outputs and their variations throughout the sunspot cycle. Likewise one wishes to know more about the variations from normal quiet sun conditions to flare conditions. It is important to obtain detail across the sun's face, and out into the corona. Of great importance is the study of solar particles and and magnetic fields associated with the sun and the clouds of particles it emits. Observations are needed on the extent of the sun's atmosphere and the variation of conditions in the solar atmosphere with distance from the sun. The effect of the sun upon the interplanetary medium is of scientific importance. Many of these observations will be done by means of satellites and space probes. But within and at the edge of the earth's atmosphere the sounding rockets have their role . Observations that from another point of wiew were a study of the earth's atmosphere and the sun's influence on that atmosphere, can be turned around to give an approach to the study of the sun itself. Rockets can be used very effectively at the time of an eclipse as the Naval Research Laboratory group has shown.

Once again the problem is broader than simply observing and collecting information. Theory should go hand in hand with experiment. One will want to explore the meaning of the data obtained, not just as they apply to the sun, but for stellar theory in general.

Rocket Astronomy

One of the most exciting possibilities of rocket sounding is that of making astronomical observations above the atmosphere in wavelengths that cannot be observed at the ground. This field of rocket astronomy, which was opened up by the Naval Research Laboratory group, is still in its infancy. The initial rocket observations will evolve in time into an important artificial satellite activity. But there is still much that the sounding rocket can do.

The Naval Research Laboratory group has shown the presence of strong ultraviolet sources in the sky. These ultraviolet radiations give a clue to evolutionary processes going on in the stars and in interstellar space. The observations are being continued by the Naval Research Laboratory and the Goddard Space Flight Center. So far, the observations have been confined to the Northern hemisphere. There is a need to extend them to the Southern hemisphere.

Certainly an important feature of satellite astronomy will be the opportunity to observe in the gamma ray region. Whether or not this might lend itself to the sounding rocket approach is a matter of question; but it may be worth exploring.

Meteorology

The weather is always at hand. Its importance is patent. Any tool or technique that can be made to aid in forecasting, or in the modification of weather, has practical value. Inthis field, the sounding rocket can indeed be of use. The moderate altitude rocket, which can be made of simple construction, can be used to measure the meteorological properties of the atmosphere above altitudes obtainable by balloons. For such observations the rocket with a peak altitude of between 60 and 70 km. can be very useful.

Sounding rockets can be used in the meteorological area both for research and for operational needs. In either case, the principal aim is the collection of data on pressure, temperature, density, water content, ozone, and winds. Also of value are observations on solar ultraviolet radiation. The rocket method is of particular importance not only because it permits one to extend the observations well above balloon altitudes, but also because the observations can be taken quickly. For operational needs, for example, for obtaining meteorological data in connection with a missile firing, the rapidity with which the data may be collected is important.

There are several approaches. To obtain upper air winds, chaff or metalized parachutes can be ejected from the flying rockets and tracked on descent. This technique is effective to perhaps 60 km altitude. Gages plus radio telemetry can be used to obtain pressure , temperature, density, water content, ozone, and solar ultraviolet. The techniques are those that have become familiar in rocketry. Here again, the rocket can propel the instruments to altitude quickly, where the measuring package can be ejected and lowered by parachute to slow its fall through the atmosphere.

In the United States, small sounding rockets have been used for collecting meteorological data on a quasisynoptic basis. In this cooperative effort, at about a half dozen stations the small rockets have been sent aloft periodically in accordance with an agreed plan. There appears to be no question but that this technique can be made operationally effective. An attractive feature of such a program is that it has both local and wide-scale value. Plainly such a cooperative program could be developed into an international cooperative effort.

For research purposes, the grenade technique of Stroud and co-workers at the Goddard Space Flight Center, gives temperature and winds to 80 or 90 km. The observational data are obtained quickly, but the reduction of these data to temperature and wind values is a lengthy process. For this reason, the grenade approach may not prove to be a particularly useful technique for operational observations.

On occasion, rocket photograpy may prove very useful for meteorological research. It is even possible that rocket photography may prove useful for operational needs. It would seem, however, that the satellite approach, illustrated by the Tiros satellite, is the long-range answer for weather photography.

In the field of meteorology, the sounding rocket will be a partner with the weather surveillance satellite in the years to come. Both will have to be supported by a strong theoretical effort. This effort will have to be devoted certainly to the physics of the problem requires theoretical attention. The masses of data that will become available from weather satellites and rocket sounding nets will prove overwhelming unless careful attention is devoted to the problem of using these data. If there is any intention of applying the data on a realtime basis to weather prediction and operational needs, the groundwork must be laid for this activity. This is a problem that has not yet been solved.

Cosmic Rays

The pioneering work of Van Allen and others in the early days of rocket sounding laid the basis for the present day satellite and space probe research on cosmic rays, radiation belts, and interplanetary particle radiations. Much of the current activity in this field will be done in balloons on the one hand, and in satellites and space probes on the other.

But there is still a role for the sounding rocket. Cosmic ray emulsions can be exposed in very high altitude sounding rockets, and quickly recovered for processing and study. Important emulsion experiments can be done in rockets that reach altitudes from a hundred kilometers to many thousands of kilometers. The very high altitude flights not only provide long exposure times, but also carry the emulsions beyond the earth's atmosphere into the lower reaches of the Van Allen belt. A subject currently of great interest is that of the solar proton beams observed in connection with large solar flares. Investigation of these solar proton beams by means of rockets is being carried out by the Goddard Space Flight Center group. Rockets bearing cosmic ray emulsions, are launched in the polar regions into the solar beam following the occurrence of a beam producing flare. After flight through the proton beam, the emulsion is recovered from the fallen rocket for study.

It may well be that there are many other uses of the rocket in connection with the study of cosmic rays. Ideas are what are needed.

Miscellaneous Problems

One can go on at length to list areas in which sounding rockets have been, and will continue to be useful. But probably enough detail has been presented above to give a feeling for the importance of the sounding rocket's role in high altitude research. We shall, therefore, simply list quickly, without detailed discussion, the remaining areas that come to mind.

The earth's magnetic field was mentioned in connection with the upper atmosphere. The field, however, has an importance also as a feature of the earth as a planet. Careful study of the earth's magnetic field may yield clues as to conditions in the interior of the earth, and as to the earth's early history. Much of the observation of the earth's magnetic field will be accomplished in artificial earth satellites. But measurements within ionospheric current sheets and electrojets, and of their effects on the magnetic field, are perhaps best done with rockets.

Investigations of cosmic dust within the atmosphere, its contribution to atmospheric ionization, and its relation to weather phenomena, are susceptible to rocket technique.

There is the field of high altitude rocket photography, which may have very useful application in the study of the earth, the atmosphere, and the weather.

Sounding rockets should be used whenever possible for flight tests of equipment, and checkout of experiments, initial surveys, etc., before an experiment is finally committed to a very expensive satellite or space probe. The sounding rocket is of use in re-entry tests, aerodynamic measurements, measurements of drag heating, etc.

How useful the sounding rocket may be for biosciences research is perhaps still an open question, although the Soviets seem to have used the rocket extensively for such studies. Certainly a great deal of thought in this matter is called for.

Finally, let us not forget that the upper atmosphere is a huge, high-vacuum laboratory provided to us by nature. Here processes can be studied without worrying about wall effects and similar laboratory vexations. By means of ejecting substances into the high atmosphere, it should be possible to make measurements on diffusion coefficients, attachment coefficients, recombination coefficients, charge exchange processes, photochemical processes, and other important physical quantities and phenomena. A beginning of this sort of experimentation has already been made by the United States Air Force and the Geophysics Corporation of America in releasing sodium vapor clouds, ethylene, nitric oxide, and other chemicals into the upper atmosphere. The potentialities for such experimentation should be explored further. More thought and more ideas are needed.

METHOD OF ATTACK

To investigate the high atmosphere by direct observation, one must get the measuring equipment up there. This is what the sounding rocket makes possible. It carries equipment aloft into the high atmosphere to the very regions where observations are to be made. Once there, the equipment must then operate automatically. The data obtained must then be retrieved. This can be done either by recording on tape or film, or in some fashion, within the rocket, and then recovering the record from the rocket after it returns to ground. To facilitate the recovery of this record, parachutes may be used to lower the portion of the rocket carrying the record. Or, what is more common, radio may be used for telemetering the information. The measured data in this case is coded within the rocket and impressed upon a radio carrier which is transmitted from the rocket to the ground. At the ground this telemetering signal is received, decoded to recover the information, and recorded in some permanent form, for example, on film or on magnetic tape.

The data, obtained either from the telemetering signal, or reclaimed from the fallen rocket, contains the information that the rocket was sent aloft to acquire. This information, however, is of little use unless one can determine where the individual measurements were actually made. It is of little value to know that the pressure measured by an instrument was so many microns, without knowing at what altitude that measurement was made. The altitude versus time history of the rocket can be obtained very accurately by a number of tracking methods. Radar or optical tracking can provide the needed data. When less accurate position information is sufficient, the rocket's trajectory may be estimated from its known performance characteristics. Or accelerometers may be included in the rocket to assist in estimating the trajectory. In some cases experimental instrumentation within the rocket will provide clues as to the trajectory followed, as for example in the case of cosmic ray counters which should show a maximum counting rate at 19 km. altitude within the earth's atmosphere, at the so-called Pfotzer maximum of cosmic ray intensity. Knowing the times at which this maximum intensity was observed on ascent and descent, and the total time spent between these two observations, one can, by fitting a free fall trajectory to these times and altitudes, obtain a fairly good estimate of the rocket's trajectory.

The roster of equipment used in rocket sounding of the upper atmosphere is a long one. It includes rockets, of course, launchers, telemeters, power supplies, command receivers and transmitters, parachutes, telemetering transmitters and ground stations, radar ground stations, radar beacons, radio velocimeters, theodolites, telescopes, ballistic cameras, ground antennae, etc. For special launches at particular geographical locations, ships may be used. Balloons can be employed to take the rocket into the stratosphere for launching there above the denser lower atmosphere. All these are basic support items. To them must be added the even longer list of measuring instruments that do research.

The heavily instrumented sounding rocket range makes it possible to obtain not only the telemetered data from the rocket, but also accurate timing, and accurate radar and optical tracking. Such a range is typified by that at Fort Churchill in Canada, which was constructed for use during the International Geophysical Year. The range was conceived, designed and constructed for the specific purpose of carrying out a series of IGY soundings in the auroral zone. It was established at the invitation of the Canadian Government. A large part of the construction work was accomplished by the United States Army Engineers, the remainder being done by private contractor. The range includes an Aerobee launching tower which was designed and built by the Aerojet General Corporation. This tower is enclosed around the bottom to permit operation in all kinds of weather. Moreover, the tower is mounted on gimbals so that it can be moved as much as 10° from the vertical in any direction. The range also has has an Aerobee preparation building, a Nike-Cajun launching facility and preparation area, a firing blockhouse protected with sand embankments, propellant and booster storage buildings, a radar system, a five-station Doppler velocity and position system (DDVAP), a ballistic camera layout, ionospheric ground stations, telemetering stations, a geophone net for sound ranging, complete communications, and a timing system. Wind data and weather information can be obtained from the Canadian Department of Transport Station at Fort Churchill. A Canadian ionosonde station is also in operation in the Fort Churchill area. Firings may be made over a land area to the south or southeast, or out into Hudson's Bay to the east and northeast. A facility such as that at Fort Churchill costs many millions of dollars to construct, and upwards of a million dollars per year to operate.

There is a great value to having a range like that at Fort Churchill for the firing of sounding rockets in the northern auroral zone. It makes possible investigations of the aurora and related phenomena, of the Arctic atmosphere, of the Arctic and auroral ionosphere, and phenomena peculiar to the polar regions. The National Aeronautics and Space Administration's Wallops Island Range is similar to that at Fort Churchill in completeness, and provides a site for rocket sounding in the temperate latitudes. There is a need for similar ranges in the southern hemisphere and on the equator.

One should hasten to point out that there are many rocket sounding projects that donot require the fully equipped range such as that just described. Much can be done with a simple rocket, its launcher, and a telemetering ground station. The rocket could be a small or moderate size solid propellant vehicle. The launcher could be a portable zero-length device that can be easily moved about and quickly set up anywhere that necessary safety conditions can be met. A portable telemetering ground station, with its antenna system and portable diesel or gasoline driven power supply can be set up in the vicinity of the launcher, or perhaps appropriately down range. Necessary timing og the launching and flight can be done with very simple equipment located with the telemetering ground station. The radio signals from WWV, or other radio time signals, can for example be used for this purpose. Heights versus time can be estimated from the known performance characteristics of the rocket and its total flight time as indicated by the telemetering. An on-board accelerometer can be used to assist in this determination. The total cost of such a minimal facility might be as low as $ 50,000, not including the cost of the rockets and their instrumentation.

Between the minimal facility and the most elaborate one there is a wide range of possibilities. Which degree of elaborateness is decided upon in any case will depend upon what are the real needs of the research to be done.

CONCLUSION

There are many problems for sounding rockets yet to solve. The satellites and space probes do not by any means put the sounding rockets out of business. Instead, they become partners. The rocket, in fact, is intermediate between the balloon and the satellite, forming a triple partnership with them. There is need for sounding rocket activities at various places around the world. Observation which have been going on in the northern hemisphere should now be extended to the southern hemisphere and to the equatorial regions.

The earth's atmosphere, for example, is an extremely complex and challenging object of study. It requires observations in many disciplines, of a bewildering array of differing quantities. The varying inputs of energy to the atmosphere must be observed and catalogued as a function of time, season, and phase of the sunspot cycle. The influence of particle radiations upon the atmosphere, and the geographical distribution of their impact upon the atmosphere must be determined. In many cases, cooperative measurements at various spots around the world are needed. Most important of all, the broad interdisciplinary approach to the study of the atmosphere must be undertaken to develop an understanding of the total atmosphere, high and low, the ionosphere, and the meteorology of the weather region in which we live.

The sun, astronomy, meteorology, cosmic rays, and various other areas offer many exciting problems for the rocket approach. The big need, of course, is for someone to peer through the maze of possibilities and see which are the really important things to do, and the best way to do them. Equally important is the need for someone to do them.

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